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# HYPERVELOCITY TRACK TESTS OF THE ABLATIVE CHARACTERISTICS OF HEATSHIELD MATERIALS FOR THE NASA GALILEO PROBE



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**ARNOLD AIR FORCE STATION, TENNESSEE**
**AIR FORCE SYSTEMS COMMAND**
**UNITED STATES AIR FORCE**

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Tests were conducted in a hypervelocity track facility to establish the ablative characteristics of the heatshield material for the NASA Galileo Probe. Data were obtained from eight shots at launch velocities of 17,500 fps and 18,000 fps. All shots were conducted using argon gas in the range tank. The test required the nosetip to be recovered intact. Measurements were made of the model velocity and in-flight surface temperature. A description of the test unit, test article, and test technique is presented herein.

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Hypervelocity Track Tests of the Ablative Characteristics of Heatshield Materials for the NASA Galileo Probe

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## NOMENCLATURE

| | |
|---|---|
| B | Bias contribution to uncertainty |
| p | Range Pressure |
| S | Precision index |
| $t_{95}$ | 95th percentile point for the two-tailed Student's "t" distribution |
| U | Total uncertainty |
| $V_i$ | Range entrance velocity |

# 1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E07, Control Number 9E07-00-1, at the request of the National Aeronautics and Space Administration (NASA/Ames Research Center), Moffett Field, CA 94035. The NASA project sponsor was Mr. Chul Park. The NASA project monitor was Mr. Charles DeRose. The results were obtained by Calspan Field Services, Inc./AEDC Division, operating contractor for the Aerospace Flight Dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee. The tests were conducted in the von Karman Gas Dynamics Facility (VKF), under AEDC Project Number C378-VG.

The tests were conducted in the Hypervelocity Track G Facility of VKF, AEDC, from June 15, 1981 through July 22, 1981. The objective of the test program was to launch specified nosetip materials through an argon atmosphere and to recover the nosetips for post-flight analysis by NASA/Ames.

A copy of the final data package for this test program has been transmitted to NASA/Ames, the sponsor of the test program. Requests for copies of the data should be addressed to the NASA Sponsor, Entry Technology Branch, Mail Stop 229-4, Moffett Field, CA 94035. A copy of the final data package is on file on microfilm at AEDC.

Presented in this report are descriptions of the test unit including instrumentation, test procedure, data reduction techniques, and data quality estimates. Sample experimental data are presented in the Appendix.

# 2.0 APPARATUS

## 2.1 TEST FACILITY

The VKF Hypervelocity Track G is described in detail in Ref. 1. The test facility consists of a launcher, a 1000-ft-long tank equipped with a track to guide the test projectile, and a recovery tube to recover the model after testing. A schematic of the test facility is shown in Fig. 1.

The launcher used was a 2.5-in.-caliber, two-stage, light-gas gun approximately 150-ft long. The test chamber consists of a 10-ft-diam tank, 1000-ft long, which is divided into three sections. Each section can be maintained at any desired ambient pressure from one atmosphere down to a few millimeters of mercury. For these tests an argon environment was provided in the test chamber. The track, which consists of four rails inside a 7-in.-ID steel tube, guides the test model through the test chamber and into the recovery tube.

In the recovery tube, the test model energy is dissipated in the compression of a gas. The components of the recovery system are (1) a 200-ft section of converging rails to "guide" the projectile into the recovery tube, and (2) a 500-ft recovery tube composed of an assembly of 10-ft sections of 2.5-in.-ID by 4.5-in.-OD stainless steel tubing. The initial 50-ft of recovery tube extends into the test environment tank and is attached to the converging rail section.

## 2.2 TEST MODELS

Two model designs were used in this test program. These two designs, one of which is a conceptually new 2-in.-diam flat-face design, are shown in Figures 2 and 3 of this report. The nosetip specimens were fabricated from carbon/carbon (multidimensional), carbon phenolic (chopped molded), and carbon phenolic ($20^{0}$ dixie-cup) materials. The model is comprised of an aluminum core, a Lexan® base and the nosetip material. These models were designed to optimize the probability of nosetip recovery.

## 2.3 ARGON ENVIRONMENT

This test program required an argon gas environment throughout the entire range tank. The test pressures used ranged from a minimum of 25 torr to a maximum of 100 torr. In order to provide the purest argon environment possible, the range was evacuated to almost a complete vacuum and then filled to the desired pressure with argon gas. In no case did air contamination exceed 1.2 torr.

## 2.4 INSTRUMENTATION

The instrumentation used in the test program included twelve X-ray stations and seven laser stations. These stations provided the necessary in-flight side view pictures, so that the nosetip characteristics could be monitored during flight. Data from the X-ray and event time recording systems were used to determine the model position, orientation, and velocity.

Other instrumentation used on this test includes image-converter camera systems at various locations along the track. These cameras view the model nosetip from almost head-on and record the brightness temperature distribution on the nosetip. These camera installations are calibrated so that surface temperature distributions can be obtained from these photographs. Test environmental conditions at test time were measured by the pressure and temperature measurement systems. Table 1 lists the instrumentation and their locations as they were used for this test program.

# 3.0 TEST DESCRIPTION

## 3.1 TEST PROCEDURE AND CONDITIONS

The test conditions for all shots are given in Table 2.

Prior to the launching of the model, the complete model assembly was dimensionally inspected. This procedure established the pretest nosetip configuration.

The model is accelerated to the desired velocity by the two-stage launcher and enters the blast tank. The function of the blast tank is to separate and contain the muzzle gases and prevent them from entering the range tank. The blast tank is separated from the range tank by a quick-operating valve which closes behind the model.

The test environment of interest is first encountered in the uprange section of the range. In this test the test environment is that of argon. After passing through the uprange section the model then enters the downrange section of the range. The uprange and downrange sections can be separated by a quick-acting valve so that a pressure differential can be maintained when desired. In this particular test program, all shots had identical pressures in the uprange and downrange sections so that the use of a quick-acting valve was not required.

At the end of the downrange section the model enters the recovery tube. The recovery tube is charged with staged pressures so that the model can be non-destructively decelerated to a stop. The recovery tube terminates into a tapered rail section which mechanically arrests the model and allows the nosetip to be recovered intact.

### 3.2 DATA REDUCTION

The model velocity history is obtained from the timing data recorded during the shot combined with the known instrumentation locations. Once the velocity history is known, other quantities of interest (e.g., drag coefficient, model ballistic coefficient, and average velocity) are computed.

The ablation characteristics of the nosetip, in this test, were to be determined by NASA/Ames.

### 3.3 DATA UNCERTAINTY

Measurement uncertainty is a combination of bias and precision errors defined as (Ref. 2):

$$U = \pm (B + t_{95}S)$$

where B is the bias limit, S is the sample standard deviation, and $t_{95}$ is the 95th percentile point for the two-tailed Student's "t" distribution, and depends on the sample size.

Estimates of the measured data uncertainties for this test are given in Table 3.

## 4.0 DATA PACKAGE PRESENTATION

The final data package for this project was prepared under separate cover. The package presents the data summarizing the test conditions and test results, including the test setup, test article information, and trajectory data. Pretest model photographs and prints of in-flight X-ray and laser photographs, along with nosetip surface temperature data were transmitted to NASA/Ames during the test program. Recovered test specimens were returned to NASA/Ames at the conclusion of the test program. Sample data are included in the Appendix of this report.

## 5.0 REFERENCES

1. Test Facilities Handbook (Eleventh Edition-Revised), "von Karman Gas Dynamics Facility, Vol. 3," Arnold Engineering Development Center, April 1981.

2. Abernathy, R. B. and Thompson, J. W., Jr., "Handbook of Uncertainty in Gas Turbine Measurements," AEDC-TR-73-5 (AD755356), February 1973.

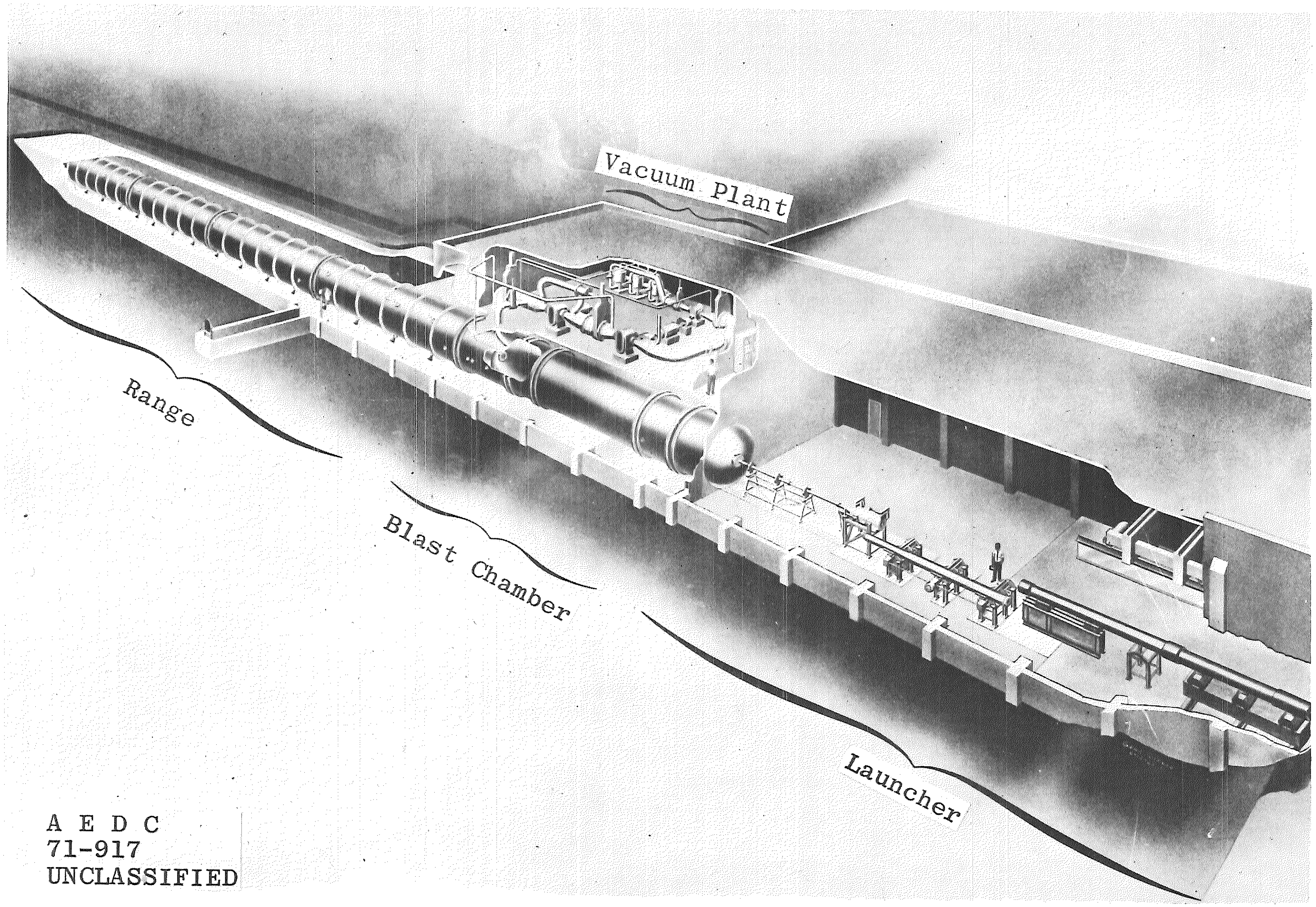



Figure 1. Range G.

# HYPERVELOCITY TRACK G

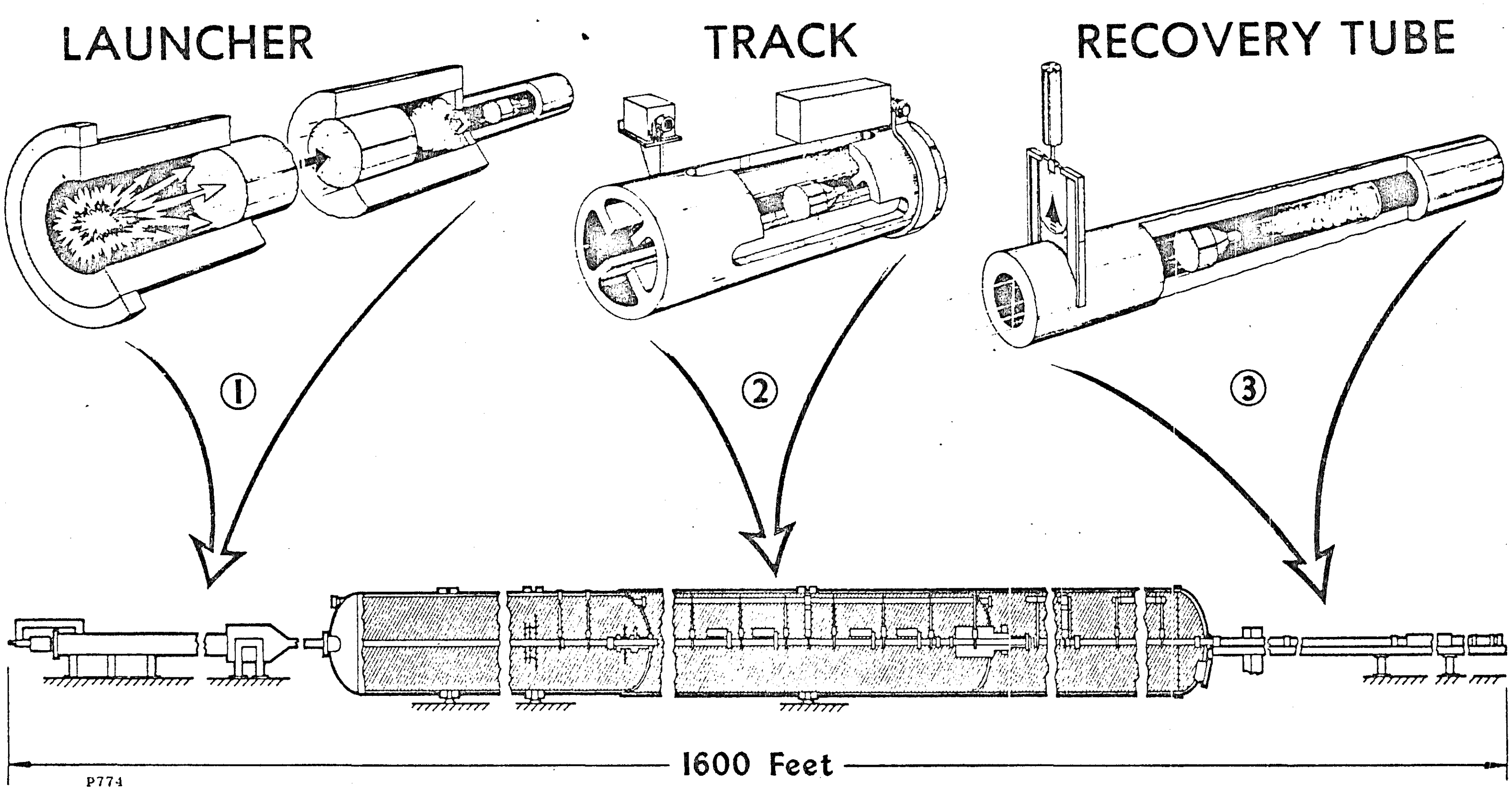



Figure 2. Hypervelocity Track G –
Track Installation

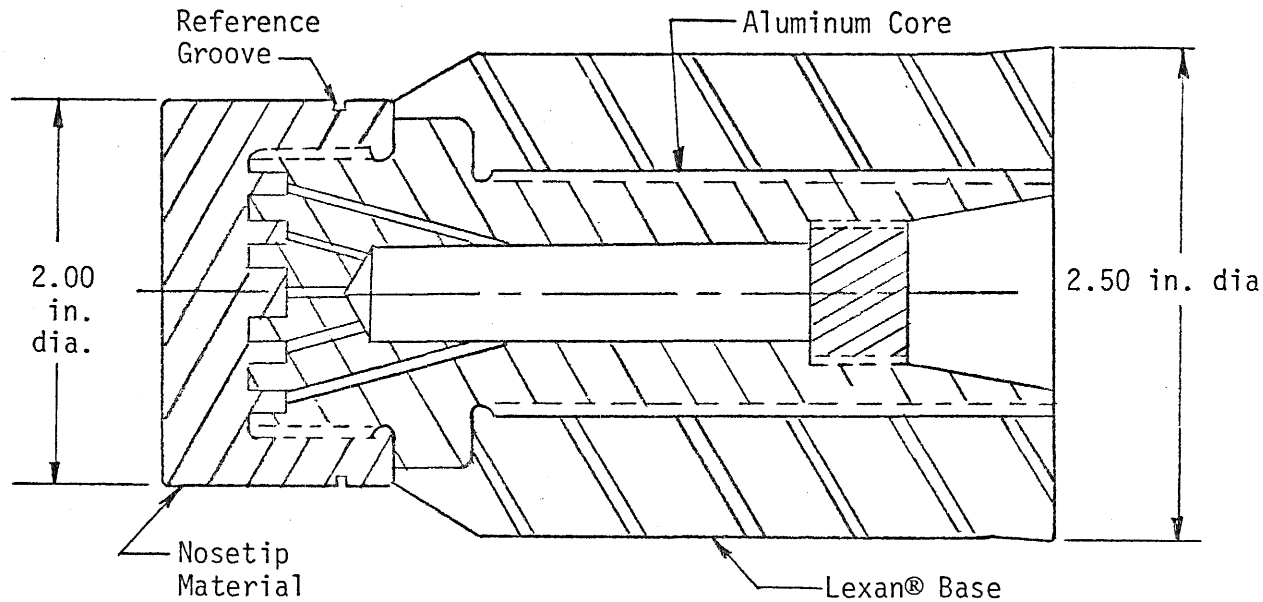



Figure 3. Model Drawing - Flat Face Design
(Full Scale)

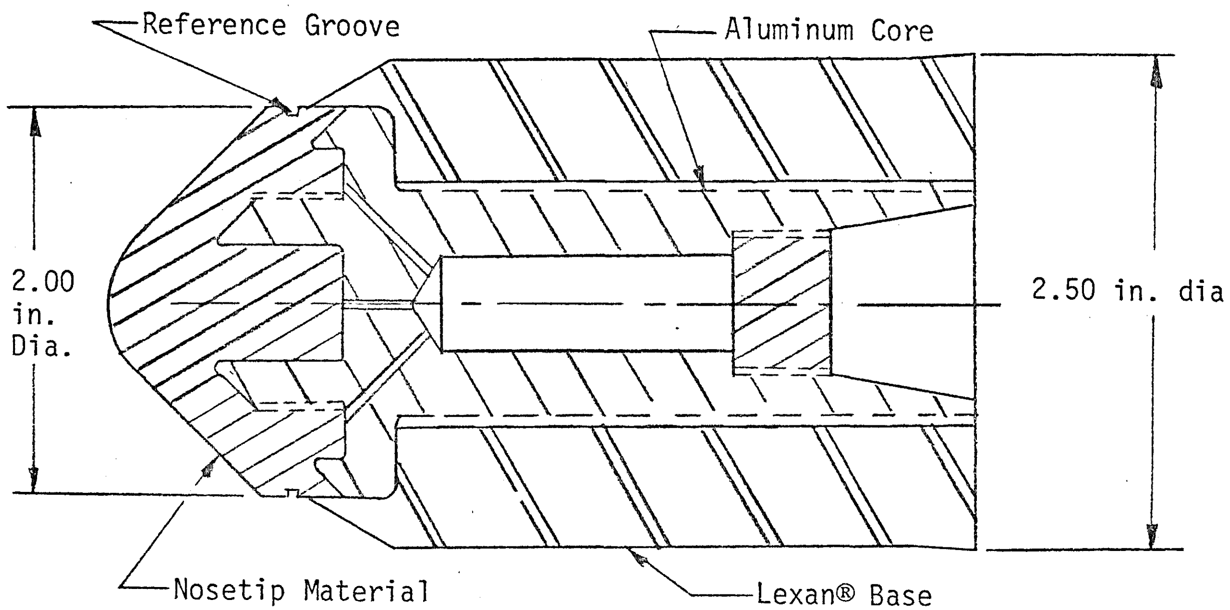



Figure 4. Model Drawing - Blunt Nose Design
(Full Scale)

TABLE 1. TEST EQUIPMENT SETUP

| Equipment Designation | | | | Equipment Location |
|---|---|---|---|---|
| Range Reference | Laser | X-Ray | IC | Distance from Range Entrance, ft |
| Launcher Exit | | | | -48.15 |
| | | X-A | | -42.61 |
| | | X-B | | -27.61 |
| Range Entrance (QOV 1 & QOV 2) | | | | 0.0 |
| | | X-1 | | 2.55 |
| | L-2 | | | 52.86 |
| | | X-2 | | 54.17 |
| | | | IC-4 | 94.63 |
| | | X-7 | | 150.92 |
| | | X-10 | | 220.92 |
| | L-11 | | | |
| QOV-3 | | | | 305.15 |
| | | X-15 | | 312.67 |
| | | X-18 | | 377.8 |
| | | | IC-20 | 395.3 |
| | L-19 | | | 398.11 |
| | | X-23 | | 472.67 |
| | L-24 | | | 492.98 |
| | | X-28 | | 577.80 |
| | | | IC-29 | 591.48 |
| | L-29 | | | 598.11 |
| | | X-34 | | 697.8 |
| | L-35 | | | 721.36 |
| | | X-40 | | 817.80 |
| | | | IC-41 | 831.48 |
| | L-41 | | | 841.35 |
| Recovery Tube Entrance | | | | 875.24 |
| QOV-4 | | | | 920.21 |

QOV = Quick-Operating Valve
IC = Image-Converter Camera

TABLE 2. TEST SUMMARY

| Shot No. | Model No. | Model Configuration and Material | Vi (fps) | p (torr) | Recovery | In-Flight Data |
|---|---|---|---|---|---|---|
| 5591 | 6608 | Flat Face/Carbon Carbon Multi-Dimensional | 17,930 | 49.2 | Yes | Yes |
| 5595 | 6607 | Blunt Nose/Carbon Phenolic Chopped Molded | 17,070 | 100.2 | Yes | Yes |
| 5599 | 6652 | Flat Face/Carbon Phenolic Chopped Molded | 17,780 | 50.3 | No | Yes |
| 5601 | 6653 | Flat Face/Carbon Phenolic Chopped Molded | 17,990 | 50.2 | Yes | Yes |
| 5602 | 6654 | Flat Face/Carbon Phenolic Chopped Molded | 17,600 | 24.8 | No | Yes |
| 5603 | 6655 | Blunt Nose/Carbon Phenolic Chopped Molded | 17,380 | 74.9 | Yes | Yes |
| 5604 | 6651 | Flat Face/Carbon Phenolic $20^{\circ}$ Dixie Cup | 17,750 | 50.3 | Yes | Yes |
| 5605 | 6650 | Flat Face/Carbon Carbon Multi-Dimensional | 17,600 | 75.0 | Yes | Yes |

NOTE: Argon gas used full range on all shots.

Table 3. UNCERTAINTY IN TEST PARAMETERS

| Parameter Designation | ESTIMATED MEASUREMENT: Precision Index (S) | | | Bias (B) | | Uncertainty $\pm(B + t_{95}S)$ | | Range | Type of Measuring Device | Type of Recording Device | Method of System Calibration |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percent of Reading | Unit of Measurement | Degree of Freedom | Percent of Reading | Unit of Measurement | Percent of Reading | Unit of Measurement | | | | |
| Range Pressure | ±1 | | 30 | 0 | | ±2 | | 10 to 300 torr | Precision Variable capacitive trans-ducer | Remote Null Reading Meter | Comparison with Secondary Standard |
| Model Velocity | ±0.005 | | 30 | ±0.0024 | | ±0.01 | | 15000 to 19000 fps | Calculated from distance-time data | | |
| Range Temperature | | ±0.90 | 20 | | ±0.10 | | ±1.98 | 50 to 100 deg F | Thermocouple | Multipoint Stripchart Servopotentiometer | Comparison with Secondary Standard |
| Model Weight | | ±1.0 | 30 | | 0 | | ±2.042 | 400 to 600 gram | Laboratory Pan Scale | Handwritten from scale | Comparison with secondary standard |
| Specimen Weight | | ±0.0012 | 30 | | 0 | | ±0.0024 | 5 to 20 gram | Laboratory Pan Scale | Handwritten from scale | Comparison with secondary standard |
| Distance Downrange | | ±0.005 | 30 | | | | ±0.01 | 0 to 840 ft | X-Ray Shadowgraphs | Photographic Film | Range Survey |
| Time Interval | ±0.0002 | ±1X $10^{-7}$ | 100 | | 0 | ±0.0004 | ± 2X $10^{-7}$ | 0 to 0.080 sec | 24-bit counter | Modcomp Computer | Comparison with primary standard |
| Brightness Temperature (Gen I System) | | ±40 | 5 | | ±25 | | ±130 | 1600 to 3300 Deg K | Photopyrometer | Photographic Film | Comparison with secondary standard |
| Brightness Temperature (Gen II Sys) | | ±40 | 5 | | ±25 | | ±130 | 1400 to 2000 Deg K | Photopyrometer | Photographic Film | Comparison with secondary standard |

(1) Listed bias estimates were assumed except for brightness temperatures.

## APPENDIX A

## REPRESENTATIVE DATA OBTAINED

The representative data shown include a sample position and velocity history (Table A-1). Figure A-1 shows a typical nosetip in-flight temperature distribution. Figure A-1 (a) shows the isothermal contours and the locations of the vertical and horizontal temperature scans which are shown respectively as Figure A-1 (b) and (c).

TABLE A-1. Velocity and Position History

INITIAL CONDITIONS: WEIGHT=4.5000D 02GRAMS PINF= 1.0020D 02TORR TINF= 5.4377D 02DEG. R

DRAG COEFF= 9.9880D-01 BASE DIAMETER= 2.5000D 00INS. DELTA TIME=1.0000D-03SEC. FINAL TIME= 7.0000D-02

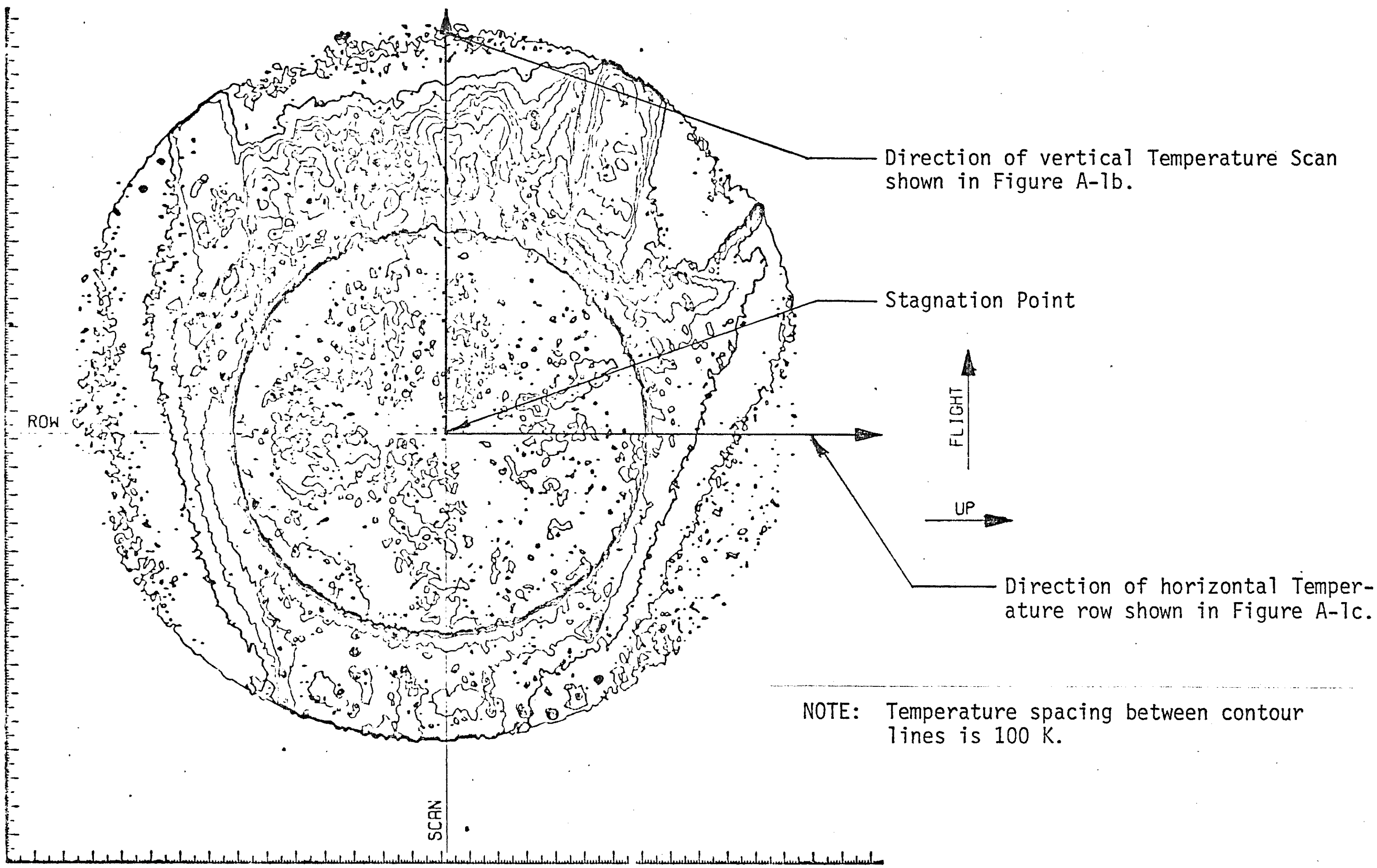
CONSTANT DRAG COEFF INITIAL VELOCITY= 1.7070D 04

SHOT 5595

| TIME SEC. | DIST FT. | VEL FT./SEC. | BETA LBS/SQ F | PSTAG ATM.. | HSTAG BTU/LB. |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 1.70700D 04 | 2.91528D 01 | 4.99452D 01 | 5.94608D 03 |
| 1.00000D-03 | 1.70700D 01 | 1.70027D 04 | 2.91528D 01 | 4.95523D 01 | 5.90034D 03 |
| 2.00000D-03 | 3.40727D 01 | 1.69360D 04 | 2.91528D 01 | 4.91640D 01 | 5.85513D 03 |
| 3.00000D-03 | 5.10087D 01 | 1.68698D 04 | 2.91528D 01 | 4.87803D 01 | 5.81045D 03 |
| 4.00000D-03 | 6.78785D 01 | 1.68041D 04 | 2.91528D 01 | 4.84011D 01 | 5.76630D 03 |
| 5.00000D-03 | 8.46826D 01 | 1.67389D 04 | 2.91528D 01 | 4.80263D 01 | 5.72265D 03 |
| 6.00000D-03 | 1.01421D 02 | 1.66742D 04 | 2.91528D 01 | 4.76558D 01 | 5.67952D 03 |
| 7.00000D-03 | 1.18096D 02 | 1.66100D 04 | 2.91528D 01 | 4.72896D 01 | 5.63688D 03 |
| 8.00000D-03 | 1.34706D 02 | 1.65463D 04 | 2.91528D 01 | 4.69276D 01 | 5.59473D 03 |
| 9.00000D-03 | 1.51252D 02 | 1.64831D 04 | 2.91528D 01 | 4.65698D 01 | 5.55306D 03 |
| 1.00000D-02 | 1.67735D 02 | 1.64204D 04 | 2.91528D 01 | 4.62150D 01 | 5.51186D 03 |
| 1.10000D-02 | 1.84155D 02 | 1.63581D 04 | 2.91528D 01 | 4.58663D 01 | 5.47114D 03 |
| 1.20000D-02 | 2.00514D 02 | 1.62963D 04 | 2.91528D 01 | 4.55205D 01 | 5.43088D 03 |
| 1.30000D-02 | 2.16810D 02 | 1.62350D 04 | 2.91528D 01 | 4.51786D 01 | 5.39107D 03 |
| 1.40000D-02 | 2.33045D 02 | 1.61742D 04 | 2.91528D 01 | 4.48405D 01 | 5.35170D 03 |
| 1.50000D-02 | 2.49219D 02 | 1.61138D 04 | 2.91528D 01 | 4.45062D 01 | 5.31278D 03 |
| 1.60000D-02 | 2.65333D 02 | 1.60538D 04 | 2.91528D 01 | 4.41757D 01 | 5.27429D 03 |
| 1.70000D-02 | 2.81387D 02 | 1.59943D 04 | 2.91528D 01 | 4.38486D 01 | 5.23623D 03 |
| 1.80000D-02 | 2.97381D 02 | 1.59353D 04 | 2.91528D 01 | 4.35256D 01 | 5.19859D 03 |
| 1.84781D-02 | 3.05000D 02 | 1.59072D 04 | 2.91528D 01 | 4.33724D 01 | 5.18076D 03 |

SECOND LEVEL CONDINTINS: PI= 1.0010D 02 DRAG COEFF = 9.9880D-01 VELOCITY= 1.5907D 04

| TIME SEC. | DIST FT. | VEL FT./SEC. | BETA LBS/SQ F | PSTAG ATM.. | HSTAG BTU/LB. |
|---|---|---|---|---|---|
| 1.94781D-02 | 3.20907D 02 | 1.58488D 04 | 2.91528D 01 | 4.30116D 01 | 5.14377D 03 |
| 2.04781D-02 | 3.36756D 02 | 1.57909D 04 | 2.91528D 01 | 4.26979D 01 | 5.10718D 03 |
| 2.14781D-02 | 3.52547D 02 | 1.57334D 04 | 2.91528D 01 | 4.23874D 01 | 5.07099D 03 |
| 2.24781D-02 | 3.68280D 02 | 1.56763D 04 | 2.91528D 01 | 4.20803D 01 | 5.03520D 03 |
| 2.34781D-02 | 3.83957D 02 | 1.56196D 04 | 2.91528D 01 | 4.17765D 01 | 4.99979D 03 |
| 2.44781D-02 | 3.99576D 02 | 1.55633D 04 | 2.91528D 01 | 4.14760D 01 | 4.96477D 03 |
| 2.54781D-02 | 4.15139D 02 | 1.55074D 04 | 2.91528D 01 | 4.11788D 01 | 4.93012D 03 |
| 2.64781D-02 | 4.30647D 02 | 1.54520D 04 | 2.91528D 01 | 4.08847D 01 | 4.89584D 03 |
| 2.74781D-02 | 4.46099D 02 | 1.53969D 04 | 2.91528D 01 | 4.05937D 01 | 4.86193D 03 |
| 2.84781D-02 | 4.61496D 02 | 1.53422D 04 | 2.91528D 01 | 4.03059D 01 | 4.82838D 03 |
| 2.94781D-02 | 4.76838D 02 | 1.52879D 04 | 2.91528D 01 | 4.00211D 01 | 4.79519D 03 |
| 3.04781D-02 | 4.92126D 02 | 1.52340D 04 | 2.91528D 01 | 3.97393D 01 | 4.76235D 03 |
| 3.14781D-02 | 5.07360D 02 | 1.51805D 04 | 2.91528D 01 | 3.94605D 01 | 4.72985D 03 |
| 3.24781D-02 | 5.22540D 02 | 1.51273D 04 | 2.91528D 01 | 3.91847D 01 | 4.69770D 03 |
| 3.34781D-02 | 5.37668D 02 | 1.50745D 04 | 2.91528D 01 | 3.89117D 01 | 4.66588D 03 |
| 3.44781D-02 | 5.52742D 02 | 1.50221D 04 | 2.91528D 01 | 3.86415D 01 | 4.63439D 03 |
| 3.54781D-02 | 5.67764D 02 | 1.49700D 04 | 2.91528D 01 | 3.83742D 01 | 4.60323D 03 |
| 3.64781D-02 | 5.82734D 02 | 1.49183D 04 | 2.91528D 01 | 3.81096D 01 | 4.57239D 03 |
| 3.74781D-02 | 5.97653D 02 | 1.48670D 04 | 2.91528D 01 | 3.78477D 01 | 4.54187D 03 |
| 3.84781D-02 | 6.12520D 02 | 1.48160D 04 | 2.91528D 01 | 3.75886D 01 | 4.51166D 03 |
| 3.94781D-02 | 6.27336D 02 | 1.47654D 04 | 2.91528D 01 | 3.73321D 01 | 4.48176D 03 |




a. Isothermal Contour

Figure A-1. In-Flight Surface Temperature Data

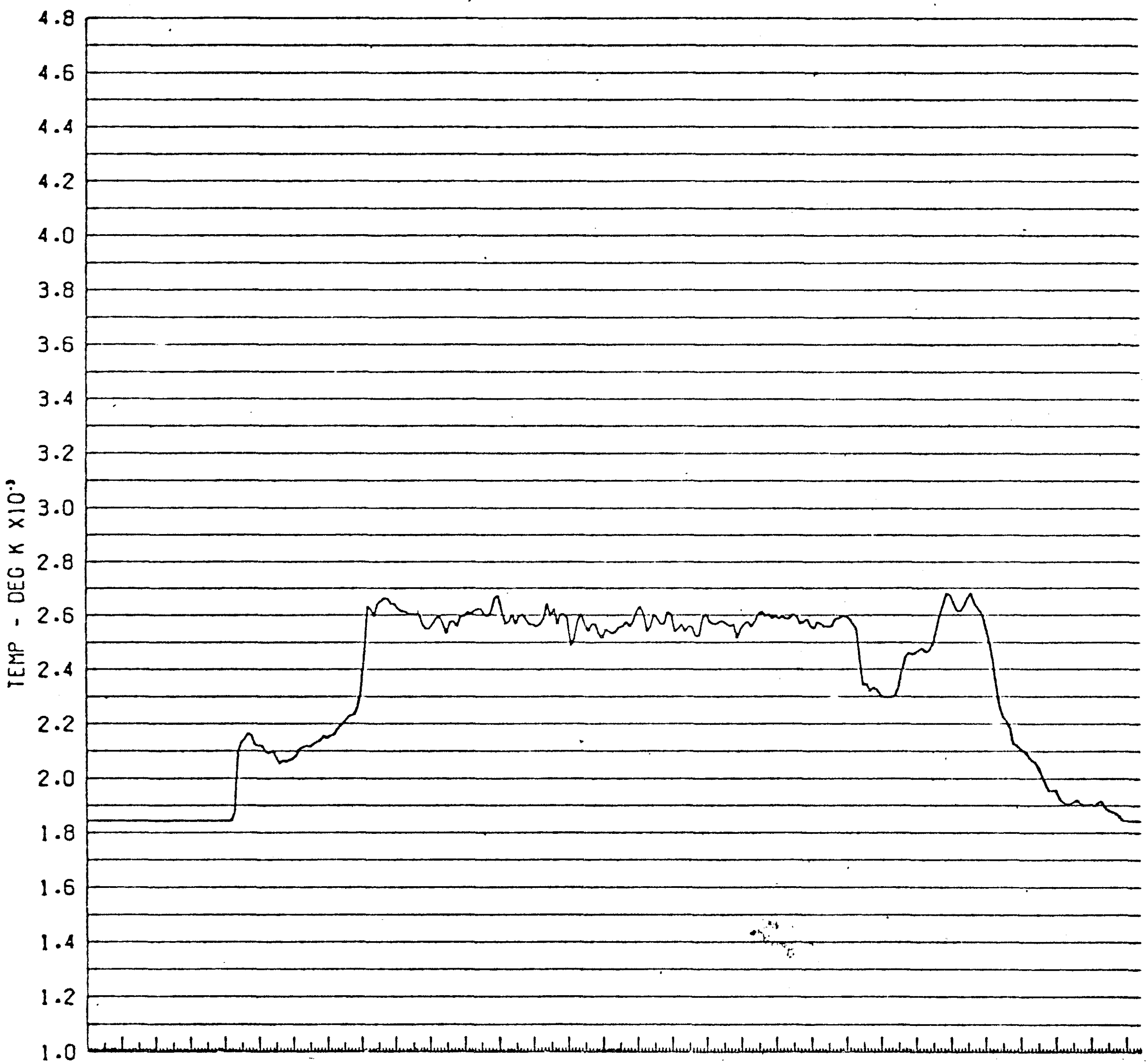



Figure A-1 Continued
b. Vertical Temperature Scan

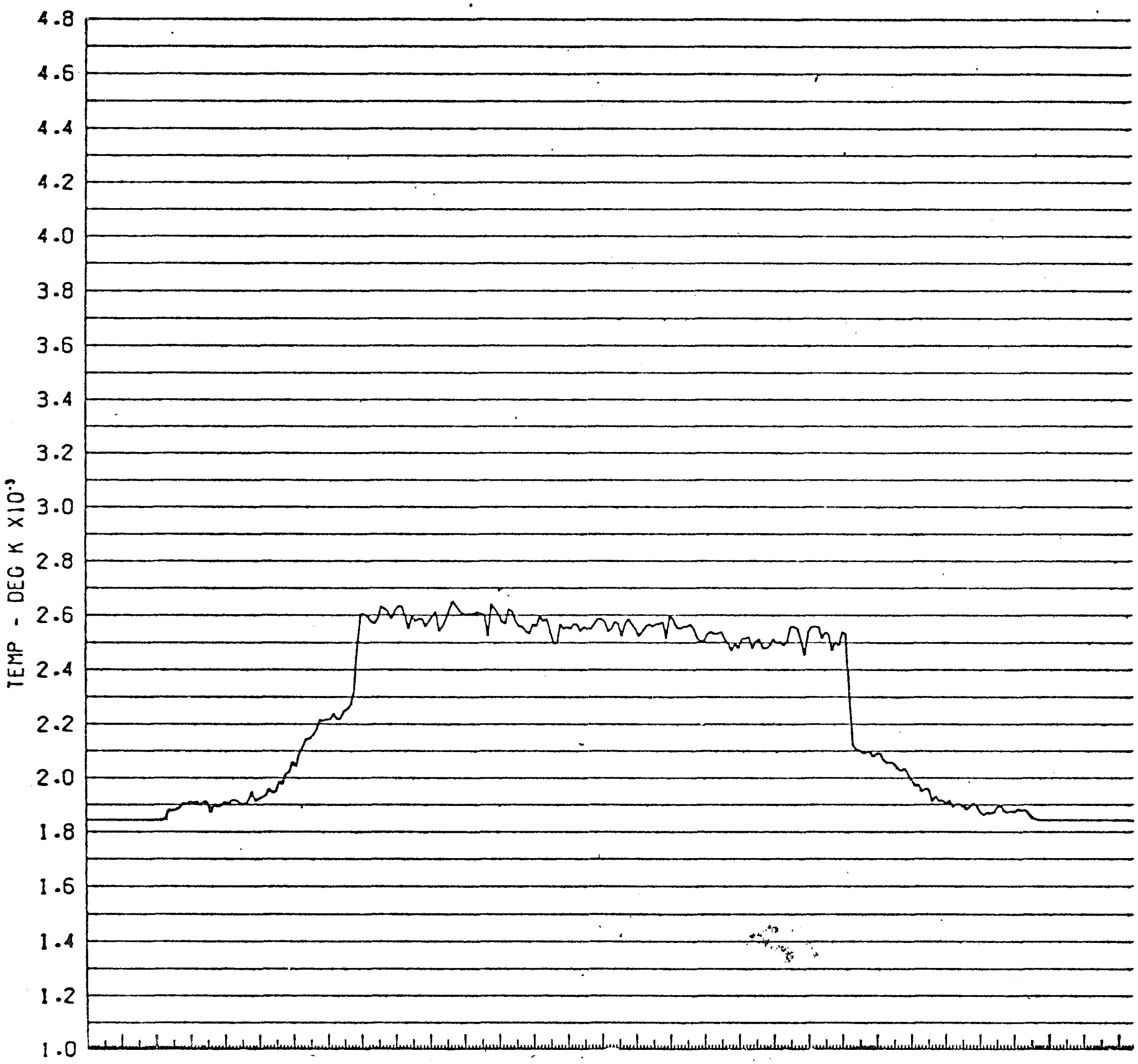



Figure A-1 Concluded
c. Horizontal Temperature Row